Photoelectron Energy Measurements Utilizing Trim Magnet Deflection onto a YAG Screen

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Abstract

The Advanced Superconducting Test Accelerator (ASTA) is housed in the NML building at Fermilab. The ASTA Front-End is a high brightness, 1.5 cell, copper, 1.3 GHz RF Gun that accelerates photoelectrons with a ~40 MV/m gradient. The Diagnostic Table is a part of the ASTA Front-End and is responsible for directing the ultra-violet (UV) laser to the photocathode and providing instrumentation for studying the electron beam. The energy of the photoelectrons can be determined by varying the current of a trim dipole magnet located downstream of the RF Gun and measuring the deflection on a YAG screen located on the Diagnostic Table.

Introduction

The ASTA Front-End generates high brightness electron bunches with a 264 nm UV laser that illuminates a cesium telluride (Cs_2Te) photocathode on the upstream wall of the 1.5 cell copper RF Gun operating at 1.3 GHz. A Diagnostic Table is immediately downstream of the RF Gun. Figure 1 shows the layout of the ASTA Front-End. The table contains 2 beam crosses (a 9-way cross and a 6-way cross), 2 trim dipole magnets, 2 cameras with associated lens tube hardware, 2 sets of horizontal and vertical beam position monitors (BPM), 2 100 liter/s ion pumps, a Laser Injection Light Box, and a Wall Current Monitor.

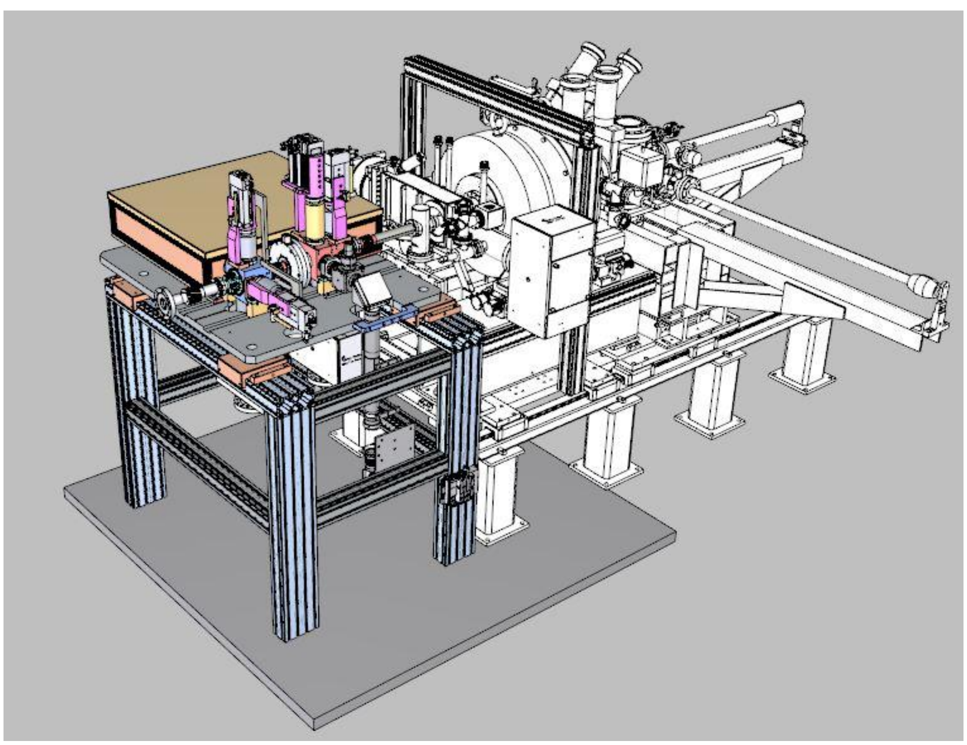

Figure 1 3D representation of the RF Gun and Diagnostic Table.

The 9-way Cross provides many functions. The upstream east port has a coated fused-silica window to allow the 264 nm UV laser to enter the vacuum system and reflect off a polished aluminum mirror, directing it to the photocathode inside the RF Gun. A double actuator is mounted on the downstream end of the cross and moves a dual position holder contained within the edge-welded bellows. The first position inserted into the cross is the target, a piece of fused-silica glass 19 mm in diameter with concentric circles 1 mm apart. An LED inside the lens tube, affixed to the downstream west side of the cross, illuminates the target and allows the focus to be set on the networked camera connected to the lens tube. The next position in the holder is the 25.4 mm diameter cerium doped YAG crystal. Since the target and the crystal are in the same plane, the camera does not require any re-adjustment. Photoelectrons deposit their energy into the crystal, causing it to scintillate. The light is reflected to the CCD camera where the spot size is measured and transverse dimensions of the electron beam are calculated. A 3D CAD representation of the 9-way Cross double actuator is shown in Figure 2.

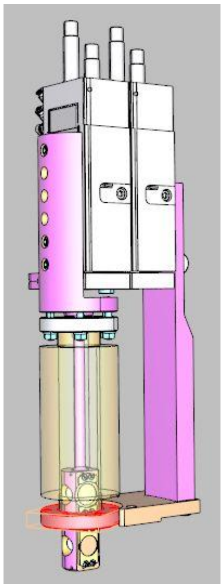

Figure 2 3D model of YAG holder and actuators.

Two sets of horizontal and vertical 5V, 10A corrector trim dipole magnets are attached to the spool piece between the RF Gun and the 9-way Cross. These trims allow for the horizontal and vertical steering of the photoelectron beam through the crosses.

The energy of the electron beam can be determined by varying the current of the horizontal or vertical trim magnet and measuring the deflection on the YAG screen 431.14 cm downstream. The energy can be calculated by

$$E\,[MeV] = \frac{299.79}{\theta} \int \mathbf{B}\; d\mathbf{l}\,\left[\frac{\mathrm{T\,m}}{rad}\right],$$

where θ is the bend angle the electrons subtend in the presence of a magnetic field from a drift-dipole.

Trim Magnets

Four trim dipole (pair) magnets are located on the upstream side of the Diagnostic Table. The magnets are comprised of copper wire wound around an iron core, which are then placed on a machined aluminum corrector coil magnet mount. The upstream pair of trim magnets, H100 and V100, are installed next to the downstream flange of the RF Gun vacuum gate valve. Magnets H101 and V101 are located on the 9-way Cross BPM flange. Figure 3 shows the trim magnets installed around the beam tube. The horizontal and vertical fields are independently adjusted with remotely controlled, regulated power supplies located outside of the ASTA enclosure.

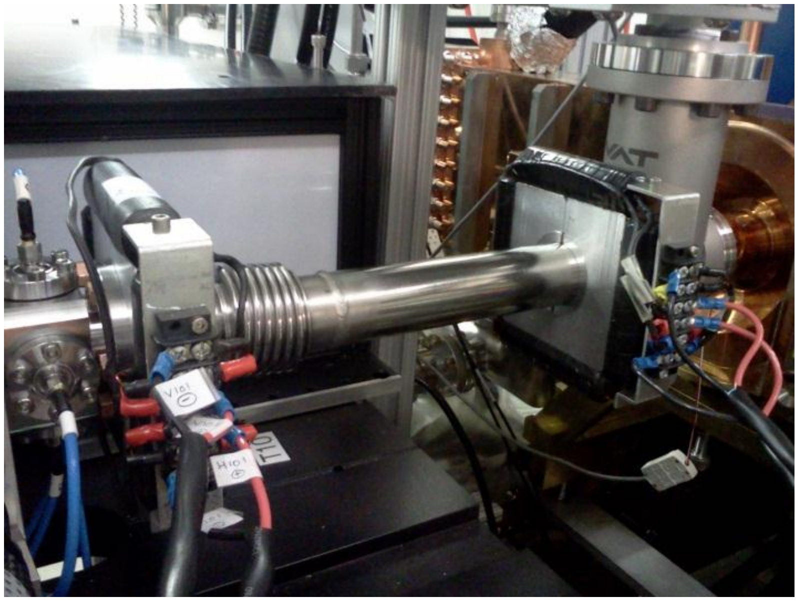

Figure 3 Trim magnets mounted around beamtube. H100 and V100 are mounted next to the vacuum valve and H101 and V101 are mounted between the beamtube bellows and the BPM housing.

Prior to installation, the fields were measured with a Hall probe on a test bench. The trim magnets were placed around a piece of 2.75” diameter G10 tube and a power supply was connected to the magnet’s leads. Data were taken at I = 2.5 A. 5 A, and 7.5 A. The Hall probe was supported by rigid foam and readings were taken at increments of 0.5” (0.25” near the peak field). Figure 4 shows the setup for measuring the fields and data from H100 is plotted in Figure 5.

Figure 4 Test bench setup for measuring the field strength of the trim magnets.

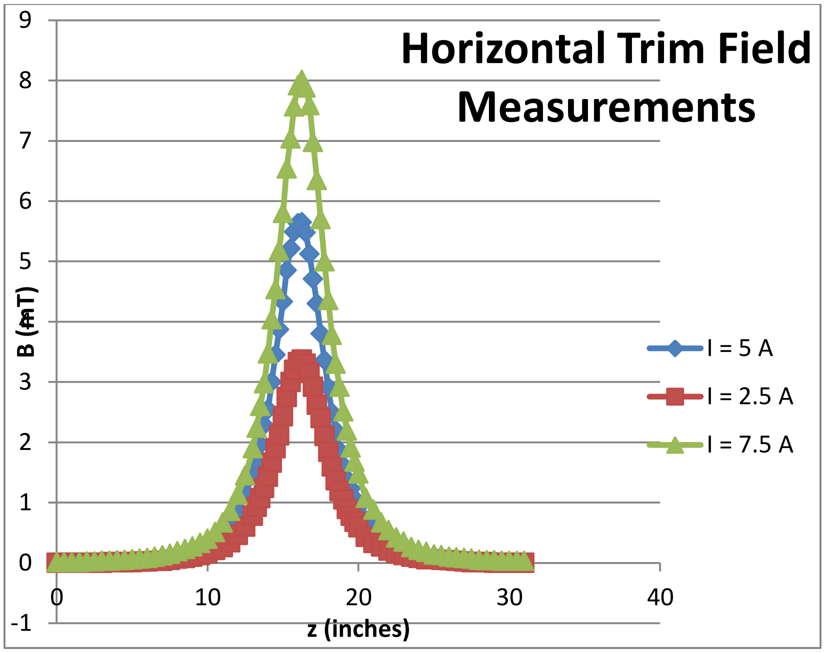

Figure 5 Trim magnet H100 field measurements at 2.5 A, 5 A, and 7.5 A.

The horizontal trim field data sets were normalized and the trim magnet exhibits a trend as seen in Figure 6. The normalized field integral for the 2.5 A data yielded

$$\int_{\infty}^{-\infty} \frac{H \cdot dz}{H_{max}} = 0.1237\ [\,m]; \quad 0.1253\ [m]\ (5A);\ 0.1268\ [m](7.5A)$$

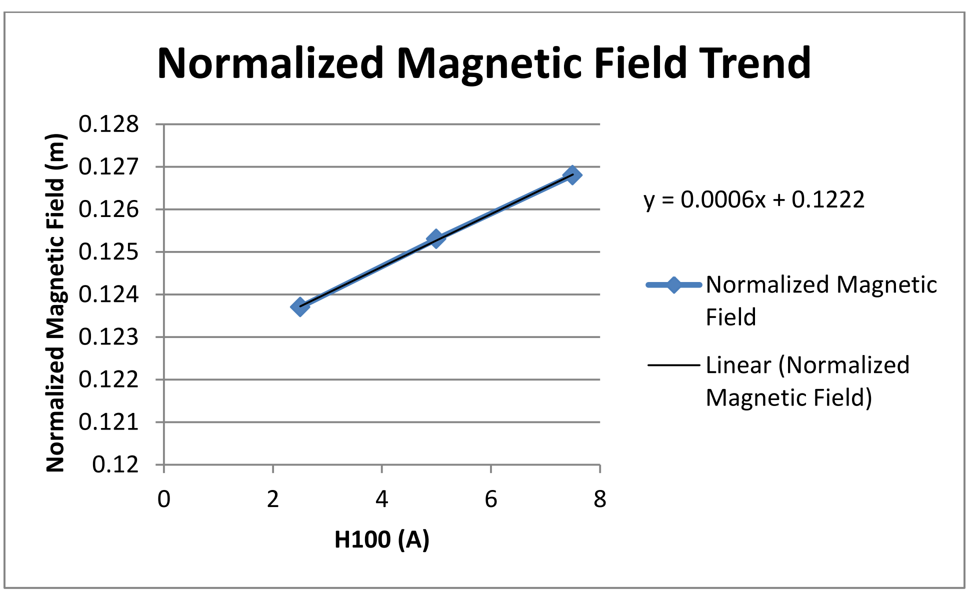

Figure 6 Trim magnet H100 normalized magnetic field plot.

The normalized magnetic field, B_n, at 1 amp can be extrapolated from the trend equation

$$B_n = 0.0006\, I + 0.1222\ [m].$$

Mitigating Hysteresis

The trim magnets exhibit a magnetic field hysteresis, Figure 7. In order to mitigate the hysteresis an ACNET sequencer aggregate was written that quickly rings down the trim magnet currents from +/-5 A to 0 A. Figure 8 demonstrates the consistency of YAG screen data when the Remove Hysteresis aggregate is run prior to data collection.

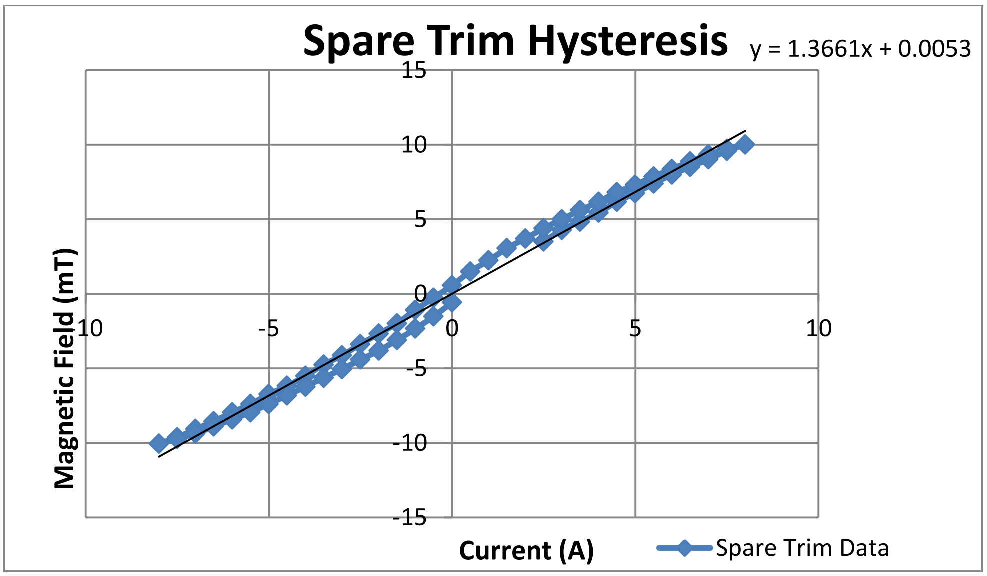

Figure 7 Hysteresis seen in spare trim magnet.

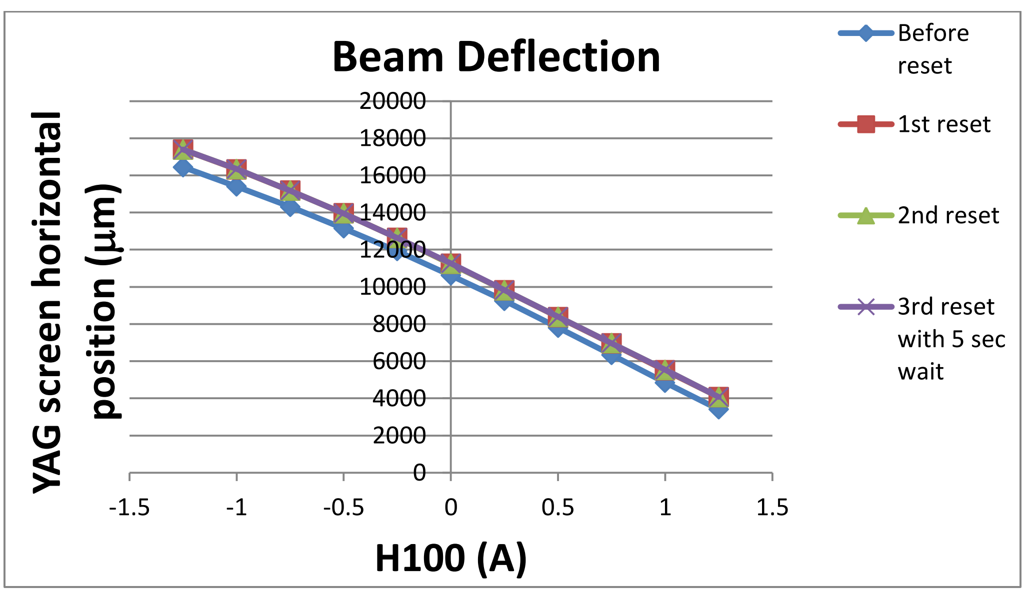

Figure 8 Without correcting for hysteresis, there is an offset in the collected position data. Data is consistent when the Remove Hysteresis ACNET sequencer aggregate is run prior to data collection.

Data Collection

There were 2 sets of data taken. The first set was taken with an uncoated molybdenum cathode and the second set was taken with a Cs_2Te coated molybdenum cathode. The 5 megapixel camera used to image the YAG screen has a conversion ratio of 9.4 μm/px. The camera data is displayed by a program called Image Tool. The beam centroid position is recorded either by utilizing the Gaussian fit or reading the crosshair value at the center of the beam profile. Figure 9 is a YAG screen shot of the beam profile with H100 at 0 A.

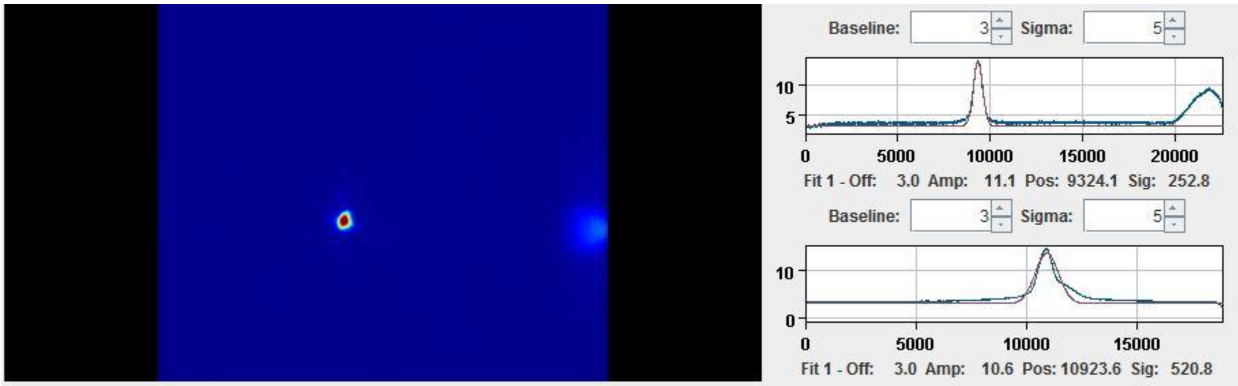

Figure 9 Image Tool shot of beam signal on YAG screen. Position of the centroid is determined by the Gaussian fit or by reading crosshair value on beam image.

A procedure was developed for taking data:

- Set operating power of RF Gun
- Open UV Laser shutter
- Insert YAG screen
- Minimize spot size with Main/Bucking solenoid mult
- Reset trim fields
- Start with H100 at -1.25 A and measure spot position on YAG screen
- Increase H100 current by 0.25 A (1.25 A max) and measure spot position on YAG screen

The procedure was slightly modified in the coated cathode mode with the addition of an RF Gun phase scan to determine the beam extinction phase, ϕ_{ext}. Once ϕ_{ext} was found, the operating phase was set to ϕ_{ext} + 52°.

Data Analysis

Once all positions for a given RF Gun cavity power have been determined, they are plotted to calculate the slope from the linear fit of the data. The slope of fit equation is the deflection value used in the energy measurement. Figure 10 is an example of the analysis of H100 deflection data for a given RF Gun cavity power.

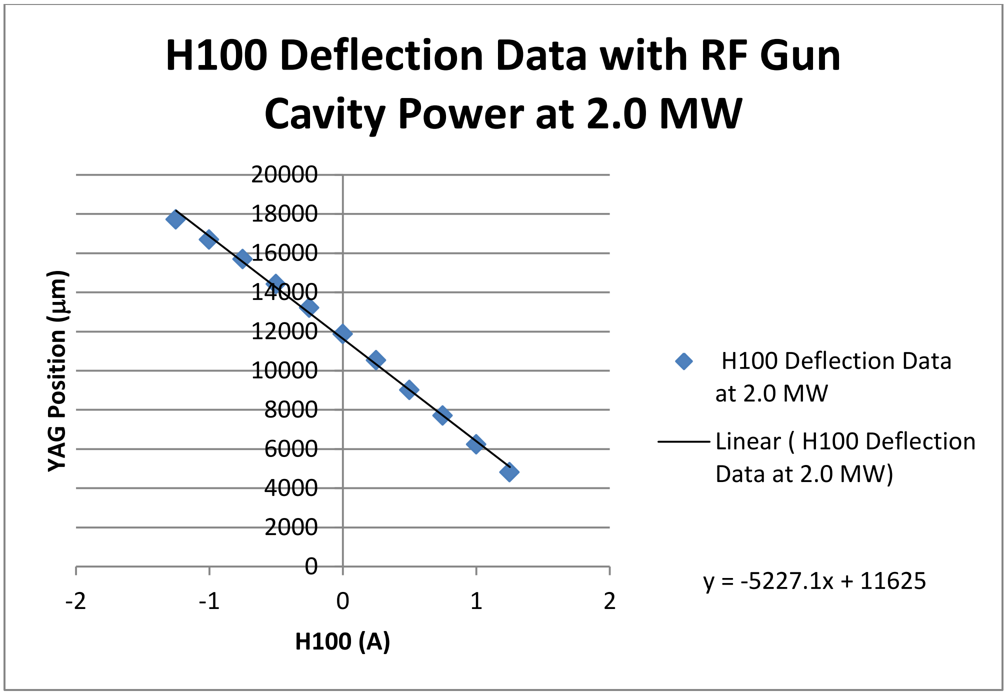

Figure 10 Deflection data plotted wrt H100 current. The linear fit in this example yields a slope of 5.227 mm/A.

As stated before, the total energy of the photoelectrons can be determined by

$$E\ [MeV] = \frac{299.79}{\theta} \int\ \mathbf{B}\ d\mathbf{l}\ [\frac{\mathrm{T\,m}}{rad}].$$

The field change at 1 A can be determined from the spare trim data, where the average field is

$$\mathrm{B[mT]} = 1.366\ \mathrm{I} + 0.005.$$

This yields a field value of 1.371 mT. The field integral change at 1 A is then the normalized magnetic field multiplied by the field change.

$$\Delta \int Bdz = (0.1228\ [m]) \cdot 1.371x10^{-3}\ [T] = 1.684x10^{-4}\ [T \cdot m]\ .$$

The total energy of the photoelectrons striking the YAG screen is then

$$E[MeV] = \frac{299.79 \cdot 0.4312[m] \cdot 1.684x10^{-4}}{x},$$

where x is the measured deflection on the YAG and 0.4312 [m] is the distance from the center of H100 to the YAG. The kinetic energy of the photoelectrons is then

$$E_k = \sqrt{(pc)^2 + (mc^2)^2} - mc^2.$$

Photoelectron Kinetic Energy Compared to the Estimated Kinetic Energy

The copper, 1.5 cell, 1.3 GHz RF Gun energy is characterized from the power measured in the cavity, P_{gun}. The peak gradient can be calculated from

$$E_{pk}\left[\frac{MV}{m}\right] = 23.6\sqrt{P_{gun}}\,,$$

where P_{gun} is measured in MW. From this, the kinetic energy can be calculated,

$$E_k[MeV] = 0.107E_{pk} - 0.07.$$

The kinetic energy calculated from the H100 deflection data sets is compared to the estimated kinetic energy the RF Gun can impart to the photoelectrons in Figure 11. The data follows the

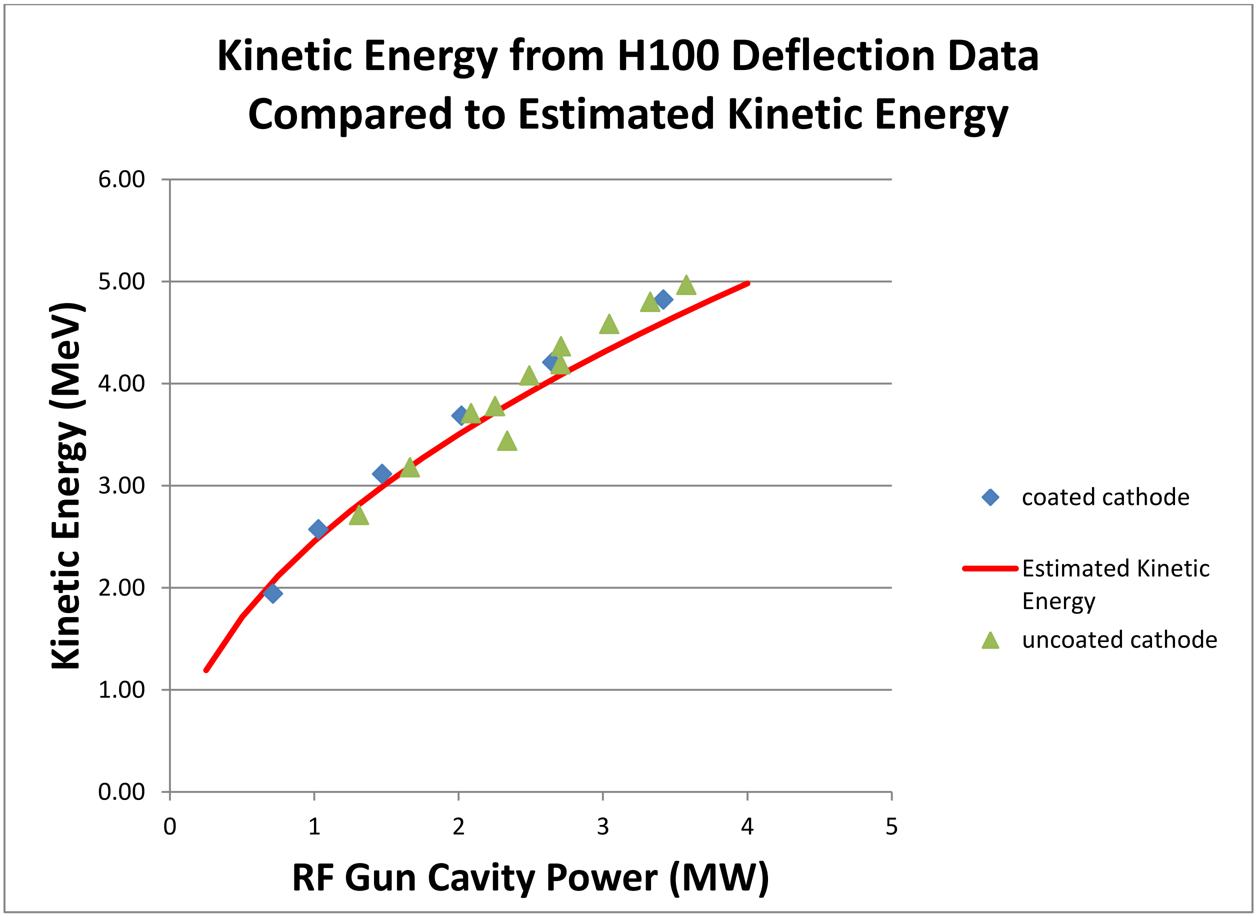

Figure 11 Kinetic energy of photoelectrons via deflection data compared to the estimated kinetic energy from the RF Gun.

Conclusion

The deflection method for determining the kinetic energy of the photoelectrons from the RF Gun is reliable and relatively quick to perform. The coated cathode data deviated from the estimated kinetic energy by an average 4.49% and the uncoated cathode data deviated by 4.47%. Even though the magnet utilized is not a drift dipole but rather a trim dipole, the energy measurement was still accurate.